

Rotation of White Dwarf Stars

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Abstract. I discuss and consider the status of observational determinations of the rotation velocities of white dwarf stars via asteroseismology and spectroscopy. While these observations have important implications on our understanding of the angular momentum evolution of stars in their late stages of evolution, more direct methods are sorely needed to disentangle ambiguities.

1. White dwarf rotation - relics of main sequence angular momentum

Rotation of white dwarfs provides an important boundary condition for the angular momentum distribution in stars from the main sequence through the asymptotic giant branch (Kawaler 2004; Tayer & Pinsonneault 2013; Cantiello et al. 2014). Despite decades of effort, our understanding of angular momentum evolution of “normal” single stars is incomplete. Complicating this effort is the difficulty of measuring rotation periods of stars. Main-sequence stars with magnetic activity allow photometric period measurement but this requires precision photometry and sufficient temporal coverage to unambiguously determine a rotation period in the face of changing spot morphology. This is difficult from the ground, but data from *Kepler* has revolutionized our study of rotation of main sequence stars (McQuillan et al. 2013, 2014; Nielsen et al. 2013; Walkowicz & Basri 2013). On the main sequence, these data have enabled gyrochronological age determinations that use calibrated angular momentum loss formalisms (Walkowicz & Basri 2013; Meibom et al. 2011).

Angular momentum transport between the core and envelope on the RGB and AGB should slow the rotation of the core, which would otherwise spin up to very short periods (Kawaler 2004). Rotation beyond the main sequence has been examined using *Kepler* data by von Saders & Pinsonneault (2013) among others. Asteroseismology has proven to be a viable tool for some RGB stars (Beck et al. 2012; Mosser et al. 2012). These studies suggest that significant angular momentum transport occurs between the shrinking core and the expanding envelope. Measuring the rotation period of white dwarfs provides useful constraints on the net angular momentum transport from the core to the envelope of stars during their post-main sequence evolution. As reviewed by Kawaler (2004), most reliable rotation periods from white dwarfs are from asteroseismology. Magnetic white dwarfs (usually with fields in excess of 10MG) also provide rotation periods through modulation of their spectra (and/or flux), but asteroseismology provides period determinations for “normal” white dwarfs.

Using observations of main sequence rotation periods as a function of stellar mass, and some simple limiting cases of angular momentum transport within stars, we can

place interesting limits on how fast white dwarfs *could* spin. The simplest limiting case is for a core whose angular momentum remains uncoupled to the envelope (except when linked by convection). This kind of analysis has been presented by Kawaler (2004), with more sophisticated scenarios using evolutionary models adding more details (i.e. Tayer & Pinsonneault 2013). The basic results are summarized in Table 1. Low mass stars must produce white dwarfs that have rotation periods longer than 5 hours. More massive stars produce white dwarfs that could have rotation periods as short as several minutes. In reality, though, any angular momentum coupling between the core and envelope on the giant branch will produce more slowly rotating cores. However, if the coupling is sufficiently strong, the remnant white dwarf could have a rotation period as long as years (Kawaler 2004; Tayer & Pinsonneault 2013).

Table 1. Lower limits to rotation period P in the cores of stars. J denotes total angular momentum for the star, HB is an abbreviation for Horizontal Branch.

Evolutionary Stage	$M < 1.2M_{\odot}$	$1.2M_{\odot} < M < 2.3M_{\odot}$	$M > 2.3M_{\odot}$
Main Sequence	dJ/dt on M.S. slow start, $P_{\text{rot}} \approx 20\text{d}$	no dJ/dt fast start, $P_{\text{rot}} \approx 20\text{h}$	no dJ/dt fast start, $P_{\text{rot}} \approx 20\text{h}$
RGB to He ign.	$\Delta M, \Delta J$ at RGB tip $P_{\text{rot}} \approx 5\text{h}$	$\Delta M, \Delta J$ at RGB tip $P_{\text{rot}} \approx 0.7\text{h}$	no M, J loss $P_{\text{rot}} \approx 0.7\text{h}$
Core He burning	degen. flash HB $P_{\text{rot}} \approx 50\text{h}$	degen. flash HB/clump $P_{\text{rot}} \approx 7\text{h}$	non-degen clump $P_{\text{rot}} \approx 0.7\text{h}$
AGB / post-AGB	env. J, M loss $P_{\text{rot}} \approx 5\text{h}$	env. J, M loss $P_{\text{rot}} \approx 0.7\text{h}$	env. J, M loss $P_{\text{rot}} \approx 0.07\text{h}$
WD mass	$M_{\text{WD}} < 0.53M_{\odot}$	$0.53M_{\odot} < M_{\text{WD}}$ $M_{\text{WD}} < 0.65M_{\odot}$	$M_{\text{WD}} > 0.65M_{\odot}$

2. Measuring white dwarf rotation periods

For all but the shortest conceivable periods, rotational broadening of white dwarf spectral lines is dwarfed by the broadened lines in these high-gravity stars. The bulk of observed white dwarf rotation periods have been determined via photometry and spectroscopy of magnetic white dwarfs, and through asteroseismology.

Magnetic white dwarfs comprise approximately 20 percent of known white dwarf stars (Kawka et al. 2007; Kepler et al. 2013). Given the intense surface gravity of white dwarfs, the surface field needs to be of order a MG or greater to influence the spectrum sufficiently for a field strength determination via spectroscopy; spectropolarimetry can reveal fields in the tens-of-kG range (Kawka et al. 2007). Simple scaling and stellar population arguments (i.e. Wickramasinghe & Ferrario 2000) suggest that these fields are difficult to generate through dynamo activity, and are likely to be remnant fields from earlier evolution as magnetic A stars on the main sequence. Manifestations of these large magnetic fields include time-dependent line broadening and polarization, and broader photometric effects (i.e. from starspots). For normal white dwarfs, near-surface dynamo activity in a convection zone could produce magnetic spots (hot or cold), which could reveal rotation through photometric variation.

Brinkworth et al. (2013) observed 30 isolated magnetic white dwarfs. They found photometric variability in nine stars with fields below 10MG, including two well below 1MG. These $\approx 1\%$ variations were uncorrelated in period or amplitude with field strength or T_{eff} . Periods ranged from less than an hour to 4 days, with two stars showing much longer periods. Howell & Holberg (2011) found a 0.26 day period in Kepler photometry of a white dwarf with a 0.3MG field. Rotation periods for magnetic white dwarfs, from Kawka et al. (2007) and later sources, are given in Table 2.

Table 2. Measured rotation periods of single magnetic white dwarfs

Star	P_{rot} [h]	Type	M [M_{\odot}]	B [MG]	T_{eff}
PG 1015	1.6	DA	0.6	120	14,000
HE 1211	2.0	DB	0.6	50	12,000
Feige 7	2.2	DAB	0.6	35	20,000
HE 1045	2.7	DA	0.6	16	10,000
PG 1031	3.4	DA	0.6	600	15,000
PG 1312	5.4	DA	0.6	10	20,000
BPM 25114	68	DA	0.6	36	20,000
KUV 813-14	429	DA	0.6	45	11,000
SDSS J000555.90	51	DQ	0.6	1.47	19,400
GD 356	2.0	DB	0.67	13	7,510
G99-37	4.1	DQ	0.67	10	6,070
G99-47	1.0	DA	0.71	29	5,790
BOKS 53856	6.14	DA	0.68	0.35	32,500
G92-40	35	DA	0.74	0.07	7,920
G195-19	32	DB	0.75	100	7,160
EUVE J0317-855	0.2	DA	1.35	300	33,000

Another sample that has yielded rotation period measurements consists of the non-radially pulsating white dwarfs (summarized in Table 3). Briefly, nonradial oscillation frequencies in an axisymmetric star are degenerate for various values of the azimuthal quantum number m for modes of the same degree l and order n . A break in that azimuthal symmetry (i.e. rotation) will cause a separation in frequency between modes of differing m by an amount equal to $m\Omega(1 - C)$ where Ω is the rotation frequency and C depends on the internal structure of the star. So, a multiplet emerges with a splitting in frequency that is proportional to Ω . For white dwarfs, $C \approx (l[l+1])^{-1}$. Thus in practice, rotationally split $l = 1$ modes become triplets, with a spacing equal to $\Omega/2$. It is this signature that reveals the white dwarf rotation periods reviewed in Kawaler (2004) and Fontaine & Brassard (2008). For rotation periods shorter than several hours, the regular period spacings (separated by successive values of n) can overlap the rotationally split multiplets. Figure 1 (left panel) shows this short rotation period confusion limit for the three most common types of pulsating white dwarfs.

Asteroseismic rotation periods are weighted averages of the internal rotation profile with depth. With a set of modes that sample different parts of the stellar interior one can, in principle, measure differential rotation in stars. Early attempts to test differential rotation in white dwarfs (i.e. Kawaler, Sekii, & Gough 1999) were inconclusive; recent attempts remain ambiguous (Charpinet et al. 2009; Corsico et al. 2011).

Table 3. Rotation periods of white dwarfs as determined via asteroseismology

Star	P_{rot} [h]	v_{rot} [km/s]	Type	M [M_{\odot}]
PG 0122	37	0.66	GW Vir	0.56
NGC 1501	28	0.87	GW Vir	0.56
PG 1707	16	1.53	GW Vir	0.56
RX J2117	28	0.87	GW Vir	0.57
PG 1159	33	0.74	GW Vir	0.60
PG 2131	5	4.89	GW Vir	0.60
EC 20058	2	8.73	DBV	0.54
KIC 8626021	41	0.43	DBV	0.56
GD 358	29	0.60	DBV	0.61
HL Tau 76	53	0.33	C-ZZ Ceti	0.55
KIC 11911480	84	0.21	H-ZZ Ceti	0.57
R548	37	0.47	H-ZZ Ceti	0.60
HS0507	41	0.43	C-ZZ Ceti	0.6
G29-38	32	0.55	C-ZZ Ceti	0.6
GD 165	50	0.35	H-ZZ Ceti	0.63
KUV11370+4222	5.56	3.14	C-ZZ Ceti	0.63
G185-32	15	1.16	H-ZZ Ceti	0.64
GD 154	55	0.32	C-ZZ Ceti	0.70
L19-2	13	1.34	H-ZZ Ceti	0.71
EC14012-1446	14.4	1.21	CH-ZZ Ceti	0.71
G226-29	9	1.94	H-ZZ Ceti	0.78
J1612+0830	0.93	18.77	ZZ Ceti	0.8
J1916+3936	18.8	0.93	ZZ Ceti	0.82
J1711+6541	16.4	1.06	ZZ Ceti	1.00

3. Observed rotation periods and their implications

The right panel in Figure 1 is a histogram of the periods measured via asteroseismology and photometry of magnetic white dwarfs, we see a distinct peak at around 1-2 days, with a median value of 28 hours. Magnetic white dwarfs cover a broader range, with most having periods less than one day. The distribution cannot be considered to represent the underlying distribution of white dwarf rotation periods.

While selection effects in this sample are horrendous, this at least demonstrates that white dwarfs *for which periods can be determined* rotate “slowly” in general. But the fact that the median rotation period is as short as a day or two means that angular momentum transport between the core and envelope is insufficient to enforce solid-body rotation on the RGB or the AGB. Cantiello et al. (2014) explore angular momentum transport in evolutionary models; such efforts may be able to accommodate this residual core rotation, but a larger sample of rotation rates for white dwarfs with better-understood systematics is needed.

Asteroseismology holds significant promise for determining a consistent white dwarf rotation period distribution – all white dwarfs are expected to pulsate when they reach the appropriate effective temperature range. The *Kepler* mission had the potential to reveal rotational modulation in white dwarfs. Several were included in the initial *Kepler* survey phase (Østensen et al. 2010); Recently, Maoz et al. (2014) reported that

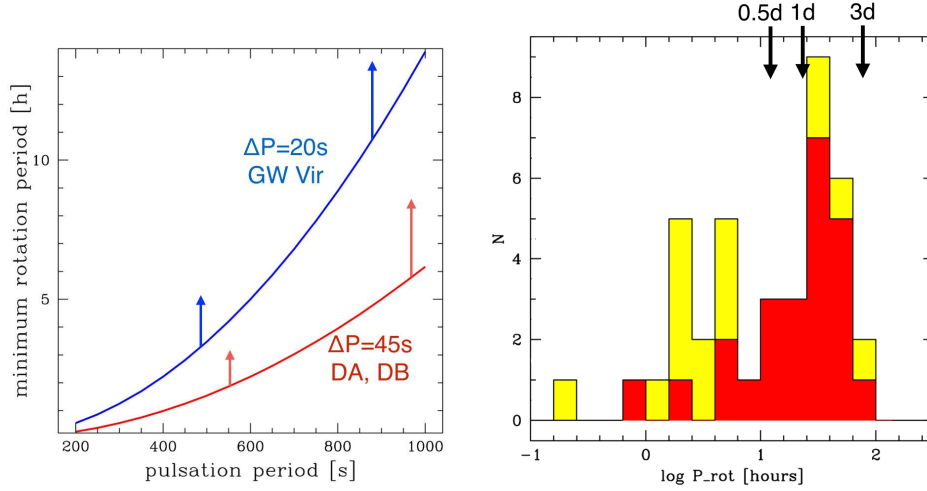


Figure 1. *Left:* Minimum rotation period that can be unambiguously determined via asteroseismology *Right:* Histogram of rotation periods. Yellow (white) are magnetic white dwarfs, while red (dark) denotes asteroseismic periods.

roughly half of those targets (7 out of 14) show photometric variations at the 0.1 to 1 ppt. The *K2* mission may observe a large sample new (and known) pulsating white dwarfs. This sample could be indispensable for validating asteroseismic rotation periods and for determining the underlying distribution of white dwarf rotation periods.

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